

On Electrical Safety in Academic Laboratories

Rodolfo Araneo¹, Senior Member, IEEE, Payman Dehghanian², Member, IEEE,
and Massimo Mitolo³, Senior Member, IEEE

Abstract—Academic laboratories should be a safe environment in which one can teach, learn, and conduct research. Sharing a common principle, the prevention of potential accidents and imminent injuries is a fundamental goal in the laboratory environments. In addition, academic laboratories are attributed exceptional responsibility to instill in students the culture of the safety, the basis of risk assessment, and of the exemplification of the prudent practices around energized objects. Undergraduate laboratory assignments may normally be framed based upon the repetition of established experiments and procedures, whereas academic research laboratories may involve new methodologies and/or apparatus, for which the hazards may not be completely known to the faculty and student researchers. Yet, the academic laboratory should be an environment free of electrical hazards for both routine experiments and research endeavors, and faculty should offer practical inputs and safety-driven insights to academic administration to achieve such a paramount objective. In this article, the authors discuss the challenges to electrical safety in modern academic laboratories, where users may be exposed to harmful touch voltages.

Index Terms—Electric shock, electrical engineering education, laboratories, safety, workstations.

I. INTRODUCTION

A. Electricity and Human Vulnerabilities

ELECTRICITY is in constant use by academic personnel (i.e., researchers and students) in engineering disciplines both within and outside the laboratory environments, the misuse or careless use of which may potentially result in significant physical harms or death. Injuries engendered by electricity include electrical shocks, burns, and falls. Electrical shocks occur when the electric current passes through the human body, the severity of which depends on:

- 1) amount of current flowing through the body;
- 2) path of the current through the body;

Manuscript received February 14, 2019; revised July 5, 2019; accepted August 5, 2019. Date of publication August 11, 2019; date of current version October 18, 2019. Paper 2019-PSEC-0204.R1, presented at the 2019 IEEE/IAS 55th Industrial and Commercial Power Systems Technical Conference, Calgary, AB, Canada, May 5–8, and approved for publication in the IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS by Power Systems Engineering Committee of the IEEE Industry Applications Society. (Corresponding author: Payman Dehghanian.)

R. Araneo is with the University of Rome “La Sapienza,” Rome 00184, Italy (e-mail: rodolfo.araneo@iee.org).

P. Dehghanian is with George Washington University, Washington, DC 20052 USA (e-mail: payman@gwu.edu).

M. Mitolo is with Irvine Valley College, Irvine, CA 92618 USA (e-mail: mitolo@iee.org).

Color versions of one or more of the figures in this article are available online at <http://ieeexplore.ieee.org>.

Digital Object Identifier 10.1109/TIA.2019.2934940

TABLE I

ELECTRICAL CURRENTS AND HUMAN BODY REACTIONS [2]

Electrical Current	Human Body Reaction
1 mA	Just a faint tingle. Threshold of sensation.
5 mA	Mild shock felt. Disturbing, but not painful. Most people can “let it go”. However, strong involuntary movements can cause injuries.
6-25 mA (females) 9-30 mA (males)	Painful shock. Muscular control is lost. This is the range where “freezing currents” start. It may not be possible to “let go”.
50-150 mA	Extremely painful shock, respiratory arrest (breathing stops), some severe muscle contractions. Flexor muscles may cause holding on; extensor muscles may cause intense pushing away. Heart fibrillation possible. Death is possible.
1000-4300 mA (1-4.3 A)	Rhythmic pumping action of the heart ceases. Muscular contraction and nerve damage occur; death likely.
10000 mA (10 A)	Cardiac arrest and severe burns occur. Death is probable.
15000 mA (15 A)	Lowest overcurrent at which a typical fuse or circuit breaker opens a circuit.
* Effects are described for voltages less than ~600 volts.	
* Higher voltages cause severe burns.	

- 3) duration of time the body is in contact with the electricity,—so called “being in the circuit,” i.e., the body becomes part of an electrical path;
- 4) the wet/dry status of the exposed body. With the direct current (dc) of 1 mA, a human can detect a “tingling” feeling, while the “let-go” median threshold for such currents is 76 mA, under which one cannot release the energized conductor.

In the case of 60-Hz alternating current (ac), the values are 0.4 and 16 mA, respectively. Women are particularly more sensitive to the effects of electrical current, where approximately 70% of the current is sufficient to result in the same effect as it has on men [1], [2]. Higher currents harvest a respiratory inhibition, then ventricular fibrillation, and ultimately a cardiac arrest. Table I summarizes the electric current levels and the corresponding human body reactions [2].

B. Electrical Hazards in Academic Laboratories

Students enrolled in undergraduate programs in colleges and universities must be introduced to the culture of laboratory safety. Students in academic laboratories may, in fact, be required to work on electrical installations and electrical equipment with no safety background. Such experiments are precisely supervised by an instructor who establishes the “Do’s” and

“Don’ts” of the procedures for students. In these laboratories, work may normally be based upon the repetition of established experiments and procedures, which are typically executed at low voltages (i.e., not exceeding 1 kV). Undergraduate students in the laboratory should never be allowed to mount circuits or equipment *live*, but only when benches are de-energized. *Dead* working will call for at least two safety barriers to be put in place to protect users [3]:

- 1) De-energization of equipment and verification that the installation is *dead*.
- 2) Securing against re-energization of the equipment.

In [3], it has been stated that “equipment must be placed in an electrically safe work condition before working on or near it,” reinforcing the concept of the safety barriers. Safety barriers shall need to be set up by an *electrically skilled person*, i.e., “a person with relevant education, knowledge, and experience to enable him or her to analyze risks and to avoid dangers that electricity could create” [3]; or by a *competent person*, defined as “who is capable of identifying existing and predictable hazards in the surroundings or working conditions, which are unsanitary, hazardous, or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate them” [3], [4]; or by a *qualified person*, i.e., “one who has demonstrated skills and knowledge related to the construction and operation of electrical equipment and installations and has received safety training to identify the hazards and reduce the associated risk” [4], [5].

Laboratory technicians, faculty members, and teaching assistants (often in charge of undergraduate laboratories) must all receive the safety training required to be able to put in safety laboratory benches by properly de-energizing and securing the supply.

In particular, qualified personnel must receive specialized training in the following.

- 1) The skills and techniques necessary to distinguish exposed live parts from other parts of the electrical equipment.
- 2) The skills and techniques necessary to determine the nominal voltage of exposed live parts.
- 3) The clearance distances specified for working on or near the exposed energized equipment and the corresponding voltages to which the person will be exposed.
- 4) Appropriate safety equipment and tools necessary to safely perform work in accordance with the standards and guidelines.

Once circuits and equipment are energized for measurements, they must be inaccessible to a person’s finger. Critical points that might allow direct contact with live parts are, however, the plugs, which make electrical connections among power supply and bench equipment. Standard plugs may offer a degree of protection IPXXB (i.e., protection against person’s access with finger) [5], [6], only if completely inserted into a receptacle, which may not always be the case in undergraduate laboratories. For this reason, safety laboratory cables should always be employed (see Fig. 1).

Plugs of safety cables are finger-safe, as they keep a degree of protection IPXXB in all conditions of insertion. Laboratory



Fig. 1. Safety laboratory cables.

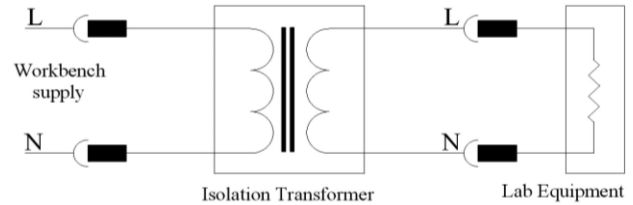


Fig. 2. Laboratory equipment electrically separated.

multimeters should also be equipped with test leads with protected tips, or with safety plugs.

In the above finger-safe conditions, no live parts are accessible during measurements, and students do not perform direct work on live parts (i.e., *live work*) [2], [3]. The finger-safe protective measure may, however, fail (e.g., due to the aging of plugs), thus users should accordingly be made aware of the potential hazards of touch voltages.

If the laboratory is not in finger-safe conditions, measurements must be considered *live working* [3] and cannot be performed by students. Only *skilled*, *competent*, or *qualified* persons (e.g., faculty) should be allowed to perform measurements, with the aid of personal protective equipment (PPE), e.g., insulating gloves.

It is important to recall that all electrical equipment in academic laboratories must be listed by a nationally recognized testing laboratory, and used in accordance with the instructions on the listing. Safety is the primary directive in an academic laboratory also considering the fact that productivity in a research lab is strictly related to the level of safety.

II. ELECTRICAL SEPARATION

The risk of electric shock might be lowered by means of electrical protective separation. Electrical separation is carried out by means of isolation transformers, which provide galvanic separation between the electrical system and the loads (see Fig. 2).

Isolation transformers used for safety have a unity turn ratio and double or reinforced insulation between the primary and secondary coils.

Isolation transformers installed at each bench provide galvanic separation and would prevent ground-fault currents from flowing; thus, persons in contact with the faulty laboratory equipment cannot receive an electric shock. The galvanic isolation provides, in fact, an electrically separated system that prevents the current from reaching the ground through the person’s body [7].

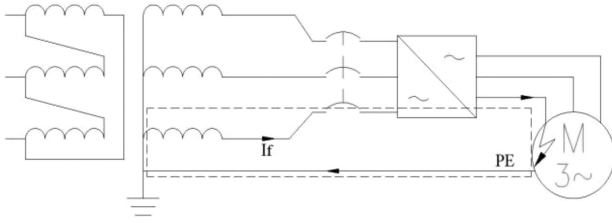


Fig. 3. Fault-loop in the presence of variable-frequency drives.

In the absence of fault currents, the fault might, however, remain undetected and unresolved. For this reason, the bench should be equipped with an insulation monitoring device that would continuously monitor the impedance-to-ground of the system and trip if such impedance would decrease below a certain threshold.

Isolation transformers would be beneficial as an additional protection against direct contact with live parts; they would also reduce short-circuit currents and the risk of electric arcs.

III. SAFETY IN ACADEMIC LABORATORIES WITH VARIABLE-FREQUENCY DRIVES

Protection against electric shock in the case of failure of basic insulation of equipment is generally carried out by automatic disconnection of supply. In TN systems in accordance with [8], and in the electrical systems adopted in the US as per [9], such disconnection is guaranteed by overcurrent protective devices, i.e., circuit breakers and fuses; Mitolo *et al.* [8] would not require residual current devices in TN systems.

The disconnection of the supply is an effective protective measure if the following condition at each bench in the laboratory is verified:

$$I_a \leq \frac{U_0}{Z_s} \quad (1)$$

where Z_s is the fault-loop impedance as seen by the fault-current (dotted line in Fig. 3); U_0 is the system nominal voltage to ground; I_a is the current causing the automatic operation of the over-current protective device within a maximum permissible disconnection time [9], [10].

If (1) is verified, touch voltages appearing on faulty laboratory equipment will not cause ventricular fibrillation. It is advisable to perform measurements of the fault-loop impedance to assess the electrical safety before opening laboratories to users [11].

In academic laboratories, variable-frequency drives (VFDs) may be used to control ac motor speed and torque for educational purposes. VFDs vary motor input frequency and voltage and may have ac-to-dc and dc-to-ac converters.

The first challenging concern in this scenario is that the determination of Z_s might not be possible because the impedance introduced by the solid-state electronics present in the VFD may not be known.

Most importantly, at the occurrence of a ground-fault at the motor (see Fig. 3), the VFD may limit its output current to about 1.5 or 1.8 times its current rating. Thus, the VFD contribution to the fault might not be detected by the upstream overcurrent

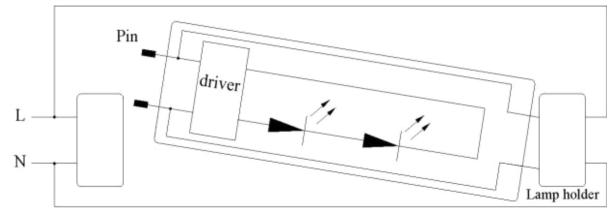


Fig. 4. Simplified circuit diagram of double capped LED linear lamp.

protective device, and the fault might not be cleared within the maximum permissible time [10].

A possible solution to reduce the risk of electric shock in academic laboratories would be the use of residual current circuit breaker with overload protection (RCCB) type F or type B [10], [12], [13] at each bench. Such RCCBs are designed for use with drives and inverters supplying motors and provide protection in case of alternating residual sinusoidal currents up to 1 kHz, pulsating direct residual currents, and smooth direct residual currents.

IV. ELECTRICAL SAFETY IN ACADEMIC LIGHTING LABORATORIES

Lighting laboratories are designed to allow students to experiment with light fixtures, perform electrical, but also photometric, measurements on fixtures, wire them, and code control strategies.

Trainers include light emitting diode (LED) fixtures, which have also become the dominant choice in all laboratories for general and task illumination due to their longer operating life and low energy consumption. LED lamps also allow a high color rendering, and color tuning, which has become an important feature in educational institutions.

The installation of double capped LED tubes (e.g., to replace linear fluorescent lamps) raises safety concerns due to the risk of electric shock. In LED double capped lamps, the electrical continuity between the two ends of the fixture may be permanent. This is not true for linear fluorescent lamps, where the electrical continuity between the two caps only occurs during the discharge through the ionized gas.

For instance, G5 type and G13 type linear fluorescents do not provide for the simultaneous insertion of both ends of LED lamps [12], [14]. If the replacement is performed when the circuit is energized, when one set of pins is inserted into the lamp holder, the contact with the uninserted pins may cause electric shock (see Fig. 4).

The steps necessary for mounting tubular LED lamps: the first instruction is “Switch off electricity” are clearly listed in [13] and [15]. This crucial step may be overlooked by users and maintenance personnel in laboratories, who may be used to replacing fluorescent fixtures, whose pins are never energized during replacement. Clearly, the risk of electric shock due to accidental contact with the energized pins can only be lowered through a specific training of laboratory users.

V. ACADEMIC RESEARCH LABORATORIES

Electrical safety in research and development (R&D) laboratories share the same common-ground rules and guidelines mentioned earlier for the undergraduate laboratories. However, additional cautions and careful considerations should be taken into account as student researchers at times are working individually on experiments directly dealing with the electrically powered equipment. This poses a potential risk of danger concerning electric safety (e.g., shocks, fires, sparks, etc.). Academic research laboratories may involve new methodologies and/or highly specialized equipment, which may not be covered by safety product standards. Thus, hazards in such laboratories may not be completely known to faculty and researchers.

The management of the safety in research laboratories may be further challenged by the irregular presence of faculty principal investigators if they no longer perform bench research. Thus, principal investigators may not be able to supervise on a daily basis laboratory safety practices [14], [16].

Already in 1951, Prof. Dalziel indicated the difficulty, if not the impossibility, to apply standard electrical safety criteria to experimental electrical laboratories, due to their unique hazards [15], [17]. The electrical safety challenges in research laboratories have been recognized by [16] and [18], which in the 2018 edition broadened article 350 to include amendments to the safety-related work requirements for ordinary workplace, to be applied to R&D laboratories.

In particular, [16] and [18] introduce the figure of the *competent person* that in addition to all the requirements of the aforementioned *qualified person* is also “responsible for all work activities or safety procedures related to custom or special equipment and has detailed knowledge regarding the exposure to electrical hazards, the appropriate control methods to reduce the risk associated with those hazards, and the implementation of those methods.” The *competent person* will enforce the use of appropriate laboratory safety practices.

Custom or special equipment for research may have exposed high-voltage terminals and/or conductors. The use of insulating blankets, covers, or barriers (i.e., physical obstructions) to prevent users from being in inadvertent contact with parts that are or may become energized is permitted in [18]. Such protective measures may provide protection against contact only from likely directions of access, and not from all directions; intentional contact by deliberate circumvention of the barriers is not prevented [6], [19]. Users performing tasks involving such special equipment must be qualified and specifically trained: training must be provided or paid by the owner of the special equipment (i.e., the school); students must be considered for all intent and purposes as regular workers.

A. Basic Rules of Engagement

When working in a research laboratory that involves experimental designs and operations, the researcher should be familiar with the equipment in the workspace, even if he/she is not directly using it. It is also very crucial to be cautious of what

other researchers, coworkers, and peers are doing and/or using in the laboratory. Working and experimenting alone with electrical equipment should be limited in such laboratory settings.

Skilled, competent, and qualified persons should be made aware of the following basic rules:

- 1) Wiring inspection of the equipment before each use.
- 2) Immediate replacement of all frayed or damaged electrical cords.
- 3) Limiting the use of extension cords to only temporary operations. Otherwise, installation of new electrical outlets should be requested.
- 4) Minimizing the potential for water or chemical spills on or near electrical equipment.
- 5) Knowing the location and how to operate the shut-off switches and/or circuit breakers.
- 6) Changing the experimental setup when ensuring the turned-OFF status of power sources, if applicable.

Qualified personnel whose work on energized equipment involves either direct contact with or contact by means of tools or materials must be trained on how to work safely on energized circuits. This includes getting familiar with the proper precautionary work practices, PPE, insulating, shielding materials, and the use of insulated tools.

Again, the class of electrical work and the level of safety requirements vary depending on the field of research. A chemist or biologist will typically work with low-energy, plug-controlled equipment. A plasma physicist, high-voltage electrical researcher, or accelerator engineer will typically work with high-voltage, high-current, and high-power electrical equipment, mandating more detailed and well-thought safety considerations and hazard controls.

Furthermore, depending on the usage and level of electricity requirement in the research laboratory settings, facilities operation and maintenance personnel must periodically verify the safety designs and, if needed, perform the design changes to the laboratory’s electrical infrastructure. Specific changes may be required when converting from dry- to wet-laboratory environment, or when a change in the electrical load exceeds the capacity in a given area. For the latter issue, a professional engineer should be employed for the assessment of the new electrical load.

B. Unidirectional Impulse Currents

Electrical equipment typically found in research laboratories may include energy storage devices, such as high-voltage capacitors and inductors [18], [20], which may cause an electric shock due to their discharge.

The unidirectional impulse currents of short duration, such as those due to a capacitor discharge, have a duration up to 10 ms is define in [18] and [21]. Dalziel [17] and [21] also indicate that the principal factor for the initiation of ventricular fibrillation due to such currents is the specific fibrillating energy F_E (2)

$$F_E = I^2 t_i = \frac{CV^2}{2R} \quad (A^2 s) \quad (2)$$

where V is the charging voltage, C is the capacitance, t_i is the shock duration, and R is the resistance of the discharging circuit, of which the person's body forms part.

The capacitor energy decays exponentially, therefore, theoretically an infinite time is required to completely discharge the capacitor. However, the duration t_i of the capacitor discharge, which is the shock duration, is assumed to be $3RC$, where RC is the time constant of the discharge circuit [18], [21].

The capacitor discharge can cause ventricular fibrillation, the likelihood of which depends on the current path in the human body, but also whether the impulse occurs within the vulnerable period of the cardiac cycle (i.e., T cycle). It is important to note that high energy impulses falling outside the heart vulnerable period can cause fibrillation even minutes after the original event [21]. A value of F_E of $0.5 \times 10^{-3} \text{ A}^2\text{s}$ is painful¹ and a value of F_E of $50 \times 10^{-3} \text{ A}^2\text{s}$ is likely to cause ventricular fibrillation, for a current-pathway hand-to-foot, and a body resistance $R = 1 \text{ k}\Omega$ are indicated in [18] and [21].

The use of automatic, mechanical discharging devices for equipment with stored energy greater than 10 J is recommended in [22]. Such limit is well below the ventricular fibrillation threshold and is, therefore, conservative. The discharging devices, contained within protective barriers, will bleed dangerous residual charge after the equipment has been de-energized.

VI. HAZARDS IN LABORATORIES DUE TO ELECTROMAGNETIC FIELD EXPOSURE

In the past years, there has been an increasing concern for potential health risks due to extremely low frequency (ELF) electromagnetic fields at power frequency (50–60 Hz) and from radiofrequency (RF) emissions radiated from several communication equipments; typical radiators may include wireless devices, such as cell phones and cordless phones, cellular antennas and towers, and broadcast transmission towers, particle accelerators. Research laboratories are no exception due to the presence of power frequency equipment, but also possibly due to full wireless coverage for, at least, voice and data transmission.

The problem of the exposure to ELF and RF electromagnetic fields is relevant, as faculty and graduate students may spend several hours a day in academic laboratories.

In 2002, the International Agency for Research on Cancer (IARC) of the World Health Organization classified the ELF magnetic fields from power lines as “possibly carcinogenic to humans (Group 2B)” [20], [23]; in 2013, IARC also placed nonionizing electromagnetic fields (EMF), ranging from 30 kHz to 300 GHz, in Group 2B [21], [24].

The guidelines published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) are the major international standards to be used as a reference, namely:

- 1) The general guidelines for limiting exposure to time-varying electric, magnetic, and EMFs that concerns exposure to fields up to 300 GHz.

¹Pain is defined in [18] as an “unpleasant experience such that it is not readily accepted a second time by the subject submitted to it.”

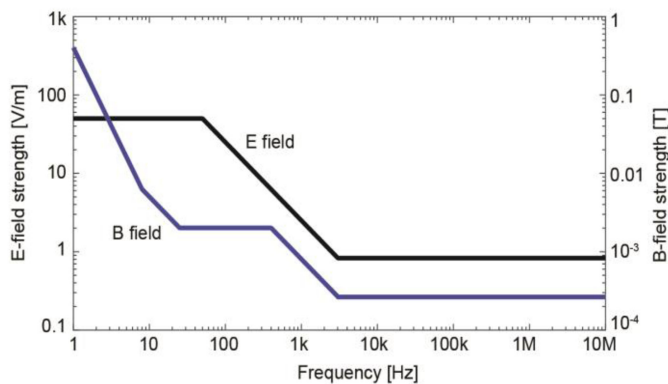


Fig. 5. Reference levels for public exposure to electric and magnetic field.

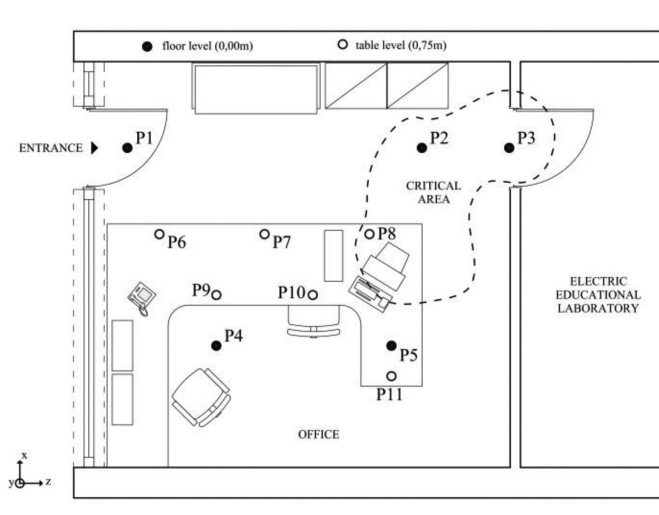


Fig. 6. Research and educational laboratory and measurement locations for B .

- 2) The specific guidelines for limiting exposure to time-varying electric and magnetic fields concerning only the issue of the exposure to LF fields from 1 Hz up to 100 kHz.

Distinguishing between nonthermal (low-intensity) biological effects in the ELF range, and thermal effects (high-intensity) for microwave exposure in the RF range, ICNIRP defined appropriate *basic restrictions* to avoid potentially disturbing effects on both central nervous system, i.e., the head, and the peripheral nervous system, i.e., the rest of the body. At each frequency, ICNIRP derived a *reference level* as a guidance figure deliberately set below the field required to produce the basic restriction. Unperturbed electric (V/m) and magnetic (A/m) fields or magnetic flux density B (T) strengths are used in the ELF range, while the equivalent plane wave power density (W/m^2) is used for RF (usually above 10 MHz). Fig. 5 shows the reference levels for public exposure. Above 100 kHz the RF-specific reference level must be considered additionally, limiting the equivalent power density below $2 \text{ W}/\text{m}^2$ up to 400 MHz.

- Before inspections, turn its power off. Turn off the circuit breakers or unplug the equipment.
In order To turn off a safety switch, use your left hand (wear insulating gloves made of leather or heavy cotton or rubber), turn your face away from the box, and pull the handle down. Circuits may discharge violently when being turned on or off and the cover to the junction box may be blown open.
- Use only tools and equipment with non-conducting handles when working with electrical devices.
- All current transmitting parts of any electrical devices must be enclosed.
- When checking an operating circuit, keep one hand either in a pocket or behind your back to avoid making a closed circuit through the body.
- Maintain a work space clear of extraneous material such as books, papers, and clothes.
- Never change wiring with circuit plugged into power sources.
- Never plug leads into power source unless they are connected to an established circuit.
- Avoid contacting circuits with wet hands or wet materials.
- Wet cells should be placed on a piece of non-conducting material.
- Check circuits for proper grounding with respect to the power source.
- Do not insert another fuse of larger capacity if an instrument keeps blowing fuses: this is a symptom requiring expert repairs. If a fuse blows, find the cause of the problem before putting in another one.
- Extension cords must be connected to a power strip equipped with a fuse.
- Do not use or store highly flammable solvents near electrical equipment.
- Multi-strip outlets (cube taps) should not be used in place of permanently installed receptacles.
- If additional outlets are required have them installed by an electrician.
- Keep access to electrical panels and disconnect switches clear and unobstructed.

Fig. 7. Example set of general rules and checklist in electrical laboratories.

TABLE II
RESULTS OF THE MAGNETIC FLUX MEASUREMENT TEST

Point	Magnetic Flux Density B (μT)	X [%]	Y [%]	Z [%]
1	2.75	2	87	11
2	50	0	14	86
3	43	6	3	91
4	3.73	1	93	6
5	10.4	7	3	90
6	1.25	0	77	23
7	3.24	1	26	73
8	10.67	1	86	14
9	1.85	5	63	32
10	4.81	3	8	89
11	7.53	3	2	95

Fig. 6 pictures actual research and educational laboratory; the switchboard supplying power to the laboratory was installed immediately above point P2. Tests consisting of magnetic flux density measurements at different locations within the laboratory were carried out. The measuring equipment was a Narda PMM 8053 with ELF probe EHP-50-C and the RF probe EP-300. Table II shows the distribution of measured values at the floor and the table level ($h = 0.75$ m). In P2 and P3, the highest magnitudes of magnetic flux were measured. Although these measurements were below the ICNIRP reference level of 100 mT, they were well above the Italian *attention value* equal to 10 μT applicable for exposure greater than 4 h per day.

Because countries in the world may have more or less stringent quantitative limits than the ICNIRP reference level, it is not

possible to generalize the results of measurements to all laboratories. The practice of the *prudent avoidance* of the EMFs must, however, be followed and measurements should be performed.

VII. WARNING SIGNS AND PSYCHOLOGICAL PERCEPTION OF DANGER

Warning signs in academic laboratories caution students and faculty of electrical hazards and instruct on the proper precautions to take to avoid accidents. Equipment with operating voltage greater than 50 V should be labeled with appropriate warning signs. Switches to turn OFF all electrical power to the equipment in case of emergency should be prominently labeled.

The installation of signs and warning labels in the workplace is part of the “*administrative controls*” per [22] and [25]. Fig. 7 demonstrates an example list of rules enforced in the electrical laboratories at the George Washington University, Washington DC, USA. Safety conveyed by signs is, however, highly dependent on person’s awareness, knowledge, and actions, and ultimately depends on the way the danger is perceived by students and faculty members. Two processes may cause students and faculty to ignore signs in laboratories: *habituation* and *interference*. Habituation is the diminishing of a physiological and emotional response to a frequently repeated stimulus: the continuous exposition to a sign “desensitizes” our response to it. Interference is when one memory causes us to have trouble remembering another: we might repeatedly see the warning signs, but we may not remember which area of the laboratory poses danger, because we are unable of making a new memory of it. Warning signs “translate” the danger with text and images, which may, however, weaken our perception and our emotional

connection to the hazard. Pieters and Wedel [26] indicate that text size matters more than picture size in attracting and focusing attention. However, the picture does matter in the initial attraction of intelligence.

The authors believe that warning signs suitable for post-millennial students may require a different strategy to improve their effectiveness. The authors are working on the implementation of *smart warning signs*, conveying the description of the danger through a cell phone app. In the vicinity of the warning sign, the app will send an alert message to the user and keep a log of the hazardous areas in the laboratory, thereby weakening the *interference* process, and possibly establishing a longer lasting focus on the hazard.

VIII. CONCLUSION

This article, based on [27], has discussed some of the major electrical safety issues concerning the academic laboratories. In undergraduate laboratories, the safety of users may be challenged by the lack of safety background, which will, therefore, require proper supervision and a list of “Do’s” and “Don’ts” detailing the lab procedures.

In academic research (R&D) laboratories, specialized equipment may not yet be covered by safety standards. In this case, the proper training of users becomes an integral part of the electrical safety measures and should be emphasized.

Energy storage devices in academic laboratories may cause an electric shock due to their unexpected discharge and electronic components may render inapplicable the disconnection of the supply as a protective measure.

This article has analyzed the above issues, with the purpose of raising the electrical safety awareness of users, and possibly establishing a common reference. Possible solutions on how to shape a culture of electric safety and increase it in academic laboratories were herein also proposed.

REFERENCES

- [1] M. Mitolo and F. Freschi, “Currents passing through the human body: The numerical viewpoint,” *IEEE Trans. Ind. Appl.*, vol. 53, no. 2, pp. 826–832, Mar./Apr. 2017.
- [2] W. B. Kouwenhoven, “Human safety and electrical shock,” *Electrical Safety Practices*, Monograph 112, Instrument Society of America, p. 93, 1968.
- [3] Operation of Electrical Installations. General Requirements,” EN 50110-1, 2013.
- [4] IEEE Guide for Maintenance, Operation and Safety of Industrial and Commercial Power Systems” IEEE 902-1998, 1998.
- [5] “General Safety and Health Provisions, OSHA 29 CFR 1926.32, 1926.
- [6] Degrees of Protection Provided by Enclosures (IP Code), IEC 60529, 2001.
- [7] M. Mitolo, “Is it possible to calculate safety: Safety and risk analysis of standard protective measures against electric shock,” *IEEE Ind. Appl. Mag.*, vol. 15, no. 3, pp. 31–35, May/June 2009.
- [8] M. Mitolo, M. Tartaglia, and S. Panetta, “Of international terminology and wiring methods used in the matter of bonding and earthing of low-voltage power systems,” in *Proc. IEEE Trans. Ind. Appl. Soc. Annu. Meeting*, May/June 2010, pp. 1–7.
- [9] NFPA 70 National Electrical Code 2017. Quincy, MA, USA, 2017.
- [10] M. Mitolo, H. Liu, and F. Shokoh, “Thermal sizing and electric shock calculations for equipment grounding conductors,” *IEEE Trans. Ind. Appl.*, vol. 49, no. 4, pp. 1720–1725, Jul./Aug. 2013.

- [11] M. Mitolo and T. Bajzek, “New generation tester to assess the electrical safety in low-voltage distribution systems,” *IEEE Trans. Ind. Appl.*, vol. 55, no. 1, pp. 106–110, Jan./Feb. 2019.
- [12] General Safety Requirements for Residual Current Operated Protective Devices, IEC 60755, 2017.
- [13] Type F and type B Residual Current Operated Circuit-Breakers With and Without Integral Overcurrent Protection for Household and Similar Uses, IEC 62423, 2009.
- [14] Lamp Caps and Holders Together with Gauges for the Control of Interchangeability and Safety—Part 1: Lamp Caps, IEC 60061, 2005.
- [15] Double-Capped LED Lamps Designed to Retrofit Linear Fluorescent Lamps - Safety Specifications, IEC 62776, 2014.
- [16] A report of the task force for advancing the culture of laboratory safety at Stanford University, Stanford University, Stanford, CA, USA, 2014.
- [17] C. F. Dalziel, “Obtaining safety in experimental electrical laboratories,” *Elect. Eng.*, vol. 70, pp. 99–103, Feb. 1951.
- [18] Standard for Electrical Safety in the Workplace, NFPA 70E, 2018.
- [19] M. Mitolo and P. Montazemi, “Electrical safety in the industrial workplace: An IEC point of view,” *IEEE Trans. Ind. Appl.*, vol. 50, no. 6, pp. 4329–4335, Nov./Dec. 2014.
- [20] L. B. Gordon, L. Cartelli, and N. Graham, “A complete electrical hazard classification system and its application,” *IEEE Trans. Ind. Appl.*, vol. 54, no. 6, pp. 6554–6565, Nov./Dec. 2018.
- [21] Effects of Current on Human Beings and Livestock. Part 2: Special Aspects, IEC 60479-2, 2017.
- [22] DOE Handbook – Electrical Safety, U.S. Dept. Energy, Washington, DC, USA, DOE-HDBK-1092-2013, 2013.
- [23] IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, Nonionizing radiation, non-ionizing radiation, Part 2: Radiofrequency electromagnetic fields, *IARC Monograph. Eval. Carcinogenic. Risks Hum.*, vol. 102, pp. 1–460, 2013.
- [24] World Health Organization, “Extremely low frequency fields environmental health criteria,” Monograph No. 238, 2007.
- [25] The National Institute for Occupational Safety and Health (NIOSH), Atlanta, GA, USA.
- [26] R. Pieters and M. Wedel, “Attention capture and transfer in advertising: Brand, pictorial, and text-size effects,” *J. Marketing*, vol. 68, no. 2, pp. 36–50, Apr. 2004.
- [27] R. Araneo, P. Dehghanian, and M. Mitolo, “Electrical safety of academic laboratories,” in *Proc. IEEE/IAS 55th Ind. Commercial Power Syst. Tech. Conf.*, May 2019, pp. 1–7.



Rodolfo Araneo (S’99–M’03–SM’09) received the M.S. (summa cum laude) and Ph.D. degrees in electrical engineering from the University of Rome “La Sapienza,” Rome, Italy, in 1999 and 2002, respectively.

In 1999, he was a Visiting Student with the National Institute of Standards and Technology, Boulder, CO, USA, where he was engaged in TEM cells and shielding. In 2000, he was a Visiting Researcher with the Department of Electrical and Computer Engineering, University of Missouri-Rolla, Rolla, MO,

USA, where he was engaged in printed circuit boards and finite-difference time-domain techniques. He is currently an Associate Professor with the DIAEE, University of Rome La Sapienza. He has authored more than 150 papers in international journals and conference proceedings. He is the coauthor of the book *Electromagnetic Shielding* (IEEE Wiley, 2008). His research interests include electromagnetic compatibility, energy harvesting and piezotronics based on piezoelectric ZnO nanostructures, and graphene electrostatics, the development of numerical and analytical techniques for modeling high-speed printed circuit boards, shielding, transmission lines, periodic structures, devices based on graphene.

Dr. Araneo serves as a Reviewer for several international journals. In 2018, he has been nominated Fellow of the Applied Computational Electromagnetics Society (ACES). Since 2015, he is the General Chair of the IEEE International Conference on Environment and Electrical Engineering. In 1999, he was the recipient of the Past President’s Memorial Award from the IEEE Electromagnetic Compatibility Society.



Payman Dehghanian (S'11–M'17) received the B.Sc., M.Sc., and Ph.D. degrees all in electrical engineering from the University of Tehran, Tehran, Iran, in 2009, Sharif University of Technology, Tehran, Iran, in 2011, and Texas A&M University, Texas, USA in 2017, respectively.

He is an Assistant Professor with the Department of Electrical and Computer Engineering, George Washington University, Washington, DC, USA. His research interests include power system protection and control, power system reliability and resiliency, asset management, and smart electricity grid applications.

Dr. Dehghanian is the recipient of the 2013 IEEE Iran Section Best M.Sc. Thesis Award in Electrical Engineering, the 2014 and 2015 IEEE Region 5 Outstanding Professional Achievement Awards, and the 2015 IEEE-HKN Outstanding Young Professional Award.



Massimo Mitolo (SM'03) received the Ph.D. degree in electrical engineering from the University of Napoli "Federico II," Naples, Italy, in 1990.

He is currently a Full Professor of electrical engineering with Irvine Valley College, Irvine, CA, USA, and a Senior Consultant in electric power engineering with Engineering Systems Inc., ESI. He has authored more than 118 journal papers and the books "Electrical Safety of Low-Voltage Systems" (McGraw-Hill, 2009) and "Laboratory Manual for Introduction to Electronics: A Basic Approach" (Pearson, 2013). His

research interests include the analysis and grounding of power systems and electrical safety engineering.

Dr. Mitolo is a registered Professional Engineer in the state of California and Italy. He is currently the deputy Editor-in-Chief of the IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS. He is active within the Industrial and Commercial Power Systems Department of the IEEE Industry Applications Society (IAS) in numerous committees and working groups. He also serves as an Associate Editor for the IEEE IAS TRANSACTIONS. He was the recipient of numerous recognitions and best paper awards, among which are the IEEE-I&CPS Ralph H. Lee Department Prize Paper Award, the IEEE-I&CPS 2015 Department Achievement Award, and the IEEE Region 6 Outstanding Engineer Award.